FINAL REPORT

USE OF MORPHOMETRIC MEASUREMENTS TO DIFFERENTIATE *ZAPUS HUDSONIUS PREBLEI* FROM *ZAPUS PRINCEPS PRINCEPS* IN COLORADO AND SOUTHEASTERN WYOMING

PREPARED FOR:

UNITED STATES FISH AND WILDLIFE SERVICE
and
PREBLE'S MEADOW JUMPING MOUSE RECOVERY TEAM

PREPARED BY:

MARY M. CONNER
Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, CO 80523

TANYA M. SHENK
Mammals Research
Colorado Division of Wildlife
317 West Prospect Road, Fort Collins, CO 80526

USE OF MORPHOMETRIC MEASUREMENTS TO DIFFERENTIATE *ZAPUS HUDSONIUS PREBLEI* FROM *ZAPUS PRINCEPS PRINCEPS* IN COLORADO AND SOUTHEASTERN WYOMING

MARY M. CONNER AND TANYA M. SHENK

ABSTRACT

Cranial and dental characteristics were measured to determine if *Zapus hudsonius preblei* could be objectively and decisively distinguished from *Zapus princeps princeps* throughout their range in Colorado and southeastern Wyoming. For an initial sample of 105 reference specimens, all mean cranial measurements of *Z. p. princeps* (n = 71) skulls were statistically larger ($P < 0.002$) than *Z. h. preblei* (n = 34). We found no differences in any of the measurements by sex and minor and random differences between the 2 observers who took measurements. However, there was an apparent gradation in the skull size of *Z. p. princeps* from Colorado to southeastern Wyoming, with Wyoming specimens being slightly smaller, in general, than those from Colorado.

We identified the initial sample of 105 specimens to species using a cross-validated discriminant function analysis (DFA) of 5 cranial measurements and an anterior medial toothfold characteristic. If each DFA run was considered separately, 21 specimens were reidentified as different from the museum tag identification for 1-3 of their DFA identifications. From examination of the data, measurement error appeared to contribute to the DFA reidentifications on a single set of measurements. Five specimens were reidentified using the mean DFA posterior probability from DFAs run separately on each set of measurements taken for each specimen. Single DFA's conducted on mean measurements for each specimen resulted in 2 of the initial sample of 105 specimens reidentified from museum tag identifications of *Z. h. preblei* to DFA identifications of *Z. p. princeps*. Seven of the 10 low-elevation southeastern Wyoming specimens were reidentified using the DFA results from the mean of the measurements. All reidentifications for the low-elevation southeastern Wyoming specimens were from museum tag identifications of *Z. p. princeps* to DFA identifications of *Z. h. preblei*.

We conclude that *Z. h. preblei* can best be differentiated from *Z. p. princeps* by a single DFA conducted on the mean of multiple cranial and dental measurements. Repeated measures avoided erroneous results due to either measurement error or recording error.

INTRODUCTION

The recent listing of Preble's meadow jumping mouse (*Zapus hudsonius preblei)* as a threatened species under the Endangered Species Act (USFWS 1998) has generated numerous surveys to better document the current distribution of *Z. h. preblei*. The historical range of *Z. h. preblei* is thought to be restricted to scattered locations in the Colorado Piedmont and southeastern Wyoming (Armstrong 1972; Clark and Stromberg 1987; Hall 1981, Krutzsch 1954; Long 1965, Fitzgerald et al. 1994). The adjacent range of the western jumping mouse (*Zapus princeps princeps*) extends farther west and north than that of *Z. h. preblei* (Armstrong 1972; Clark and Stromberg 1987; Hall 1981, Krutzsch 1954; Long 1965) at elevations greater than 1,830 m in Colorado (Fitzgerald et al. 1994). Captures of *Z. h. preblei* and *Z. p. princeps* (as identified by museums) have occurred as close as 5 km within the same drainage (Armstrong 1972), and possibly sympatrically (R. Schorr; Colorado Natural Heritage Program, personal communication). Because characteristics are similar for the 2 species, ambiguity exists as to field identification of *Z. h. preblei* relative to *Z. p. princeps*, especially in areas of the upper elevational limit of *Z. h. preblei*. Thus, it may be possible that *Z. h. preblei* are being misidentified as *Z. p. princeps* and vice versa. This difficulty in positively identifying to species in the field motivated the need to develop an objective method for positively differentiating *Z. h. preblei* from *Z. p. princeps*.

Morphometric characteristics have proven useful in providing information used to differentiate Z. *hudsonius* from *Z. princeps*. Hafner et al. (1981) found cranial measurements provided delineation of 3 similar species/subspecies of jumping mice in New Mexico. Fitzgerald et al. (1994) described *Z. h. preblei* as having a smaller, narrower braincase and smaller molars then *Z. p. princeps*. Thus, it is likely that cranial measurements may provide the information necessary for definitive identification.

Positive identification of *Z. h. preblei* from *Z. p. princeps* is important because one apparently is rare and 'threatened' whereas the other is common. Appropriate management requires positive identification of species. Therefore, the primary objective of this study was to determine whether it is possible to positively distinguish *Z. h. preblei* from *Z. p. princeps* based on morphometric measurements taken from prepared skulls. An additional objective of this study was to evaluate variation in measurements among and within measurers to provide guidelines on how to collect morphometric data for future studies. Lastly, once the method was developed we wanted to use it to determine the identification of *Zapus* specimens collected from low-elevation sites in southeastern Wyoming. Such areas seemingly provide the greatest area of potential overlap of *Z. h. preblei* and *Z. p. princeps* and there is controversy as to whether *Z. h. preblei* currently exists in southeastern Wyoming.

MATERIALS AND METHODS

Data Collection

Museum specimens of *Z. p. princeps* and *Z. h. preblei* were gathered from collections at the Denver Museum of Nature and Science (DMNS), University of Colorado at Boulder (CU), and the University of Kansas (KU) (Appendix I). All specimens had been collected from either Colorado or southeastern Wyoming. To avoid using specimens from areas of potential range overlap, we only used specimens of *Z. p. princeps* collected above 2,400 m for our initial sample. After the elevation criterion was met, we chose *Z. p. princeps* specimens randomly by museum from high elevation locations in Colorado and Wyoming (Fig. 1). Specimen locations (Fig. 1) were based on coordinates from the museum tag, a locality description on the museum tag making it possible to find a location, or personal communication (C. Meaney). All museum-tagged *Z. h. preblei* specimens with intact skulls were measured (Fig. 1). Only data collected on adult mice were used in the analyses to avoid confounding species identification with age of the specimen. A specimen was identified as an adult if it showed at least slight wear on M^3 (Krutzsch 1954).

We attempted to take measurements on 133 skulls, but due to the tooth wear criterion and damage, only 121 skulls had complete sets of cranial measurements taken. Therefore, only these 121 skulls were identified to species using discriminant function analysis (DFA) because DFA requires a complete set of data for identification. For consistency, we only used these same 121 skulls in all other analyses. These 121 skulls included an initial sample of 105 skulls from which the DFA was developed, and a subsequent sample of 16 skulls used to identify low-elevation, southeastern Wyoming specimens (described below). For the initial sample of 105, 71 specimens were identified by museum tag as *Z. p. princeps* and 34 specimens were identified by museum tag as *Z. h. preblei*. The initial sample of 105 specimens came from Colorado ($n = 87$) and high-elevation areas (>2,400 m) in southeastern Wyoming ($n = 18$). For the subsequent low-elevation southeastern Wyoming sample, 10 specimens were identified by museum tag as *Z. p. princeps* and 6 *Zapus* specimens had not been identified to species. The 16 specimens from low elevation areas near Laramie and Cheyenne, Wyoming were gathered in 2 ways. Six voucher specimens were collected during the summer trapping season in 1999 and 2000, and 10 specimens were from the museum collection at the University of Kansas (Fig. 1). Fifteen of these Wyoming specimens were from elevations <2,260 m and 1 was collected at 2,500 m (this specimen was collected in 1999).

All specimen measurements were conducted "blindly"; that is, the observer taking measurements did not know species identification or collection location from the museum tag. Cranial measurements were recorded by their unique museum catalogue number. Measurements were taken using digital calipers and recorded to the nearest hundredth of a millimeter.

We attempted to collect 12 cranial measurements (Fig. 2 and Appendix II) and 2 dental characteristics. Following Hafner et al. (1981), we measured condylobasal length, zygomatic breadth, least interorbital breadth, length of upper molar toothrow, width of P^4, length of incisive foramina, least interbullar width, and moment arm of masseter (Fig. 2). Additionally, we measured palatal breath at P^4 (Whitaker 1972), palatal length, length of lower molar toothrow, width of incisive foramina (Fig. 2), presence or absence of anterior median toothfold (Fig. 3) (Klingener 1963), and presence or absence of tooth wear on M^3 (Krutzsch 1954).

Independent of the time when skulls were measured, we recorded all museum tag data for each specimen measured, including age, sex, museum, location (in UTM coordinates), elevation, and species identification. If collection location coordinates were not directly recorded for a specimen, where enough information was available, we estimated the collection location by plotting the location description on a 1:24,000 map and recording UTM coordinates and elevation.

To evaluate measurement variation, 2 mammalogists experienced in museum work measured each specimen 4 times. Specimens were placed in a line in random order and both observers (mammalogists) took each skull measurement twice. This procedure was then repeated with each observer starting at the opposite end of the line of specimens to repeat each set of measurements for each skull. Thus, each skull measurement was taken 8 times, 2 times by each of 2 observers over 2 different time periods. These data were used to evaluate within- and between-observer measurement variations.

Data Analysis

We used least-square means with the variance corrected for repeated measures in PROC MIXED (Littell et al. 1996) to estimate mean cranial measurements and their 95% confidence interval (CI). Species, state, sex, observer, and sex×species were included in the mixed model as fixed effects, while specimen, nested within species, was modeled as a random effect. Using the same model as for the mean estimates, we used least-square mean differences in PROC MIXED (Littell et al. 1996) to estimate differences in mean cranial measurements by species, state, sex, and observer. Measurements from all 105 initial skulls were used to estimate these mean and mean difference estimates. Type III sum-of-squares were used for all hypothesis tests to account for unequal sample sizes.

Because the presence or absence of the anterior median toothfold was considered a potential key for identifying *Z. h. preblei* from *Z. p. princeps* (Fig. 3), we evaluated this characteristic separately. We recorded a 1 if the toothfold was present and a 0 if absent. Observers only evaluated this characteristic one time as they worked down the line of specimens; thus, there were 4 toothfold evaluations per skull (2 per observer). A mean of the 4 evaluations was calculated; if the mean was >0.5, the toothfold was identified as present, otherwise it was identified as absent.

We used DFA to calculate the probability (called posterior probability in DFA) that a specimen was *Z. p. princeps* (the probability a specimen was a *Z. h. preblei* was 1 minus the probability that it was a *Z. p. princeps*). DFA develops a function to identify each observation into a group for a set of observations containing 1 or more quantitative and/or categorical variables and having a prior probability of group membership (Manly 1986). We used the proportion of each species in the sample for prior probability of group membership, which implies no knowledge of which species a specimen should be identified as. To avoid the bias of overestimating intertaxon distinctiveness often encountered in DFA (Manly 1986, Lance et al. 2000), we performed a jackknifing cross-validation procedure using the CROSSVALIDATE and CROSSLISTERR options in PROC DISCRIM (SAS Institute 1990) to identify to species. The jackknife cross-validation procedure involves removing 1 observation from the data set and then identifying that observation based on a DFA from the remaining data. That observation is then returned to the data set and the entire procedure is repeated for each observation (Lance et al. 2000).

We used a model selection procedure to develop a DFA. We included all 12 cranial measurements plus the toothfold character and used forward, backward, and stepwise selection to choose the best distinguishing measurements for the DFA (Manly 1986, SAS Institute 1990). After the DF was developed, we ran the DFA using 2 approaches. First, we ran a separate DFA for each set of cranial measurements; thus there were potentially 8 DFAs performed for each specimen. To account for measurement variation, we averaged DFA posterior probabilities for each set of measurements taken on a single skull and used this mean to identify each specimen. If the DFA mean posterior probability was >0.5, then the specimen was identified as *Z. p. princeps*, otherwise it was identified as *Z. h. preblei*. For the second approach, we ran a single DFA on the mean of the 8 measurements taken for each specimen. If the DFA posterior probability was >0.5, the specimen was identified as *Z. p. princeps*, otherwise it was identified as *Z. h. preblei*.

In southeastern Wyoming, it was unclear whether *Z. p. princeps* or *Z. h. preblei* occurred at lower elevations (<2,300 m). We used the discriminant function developed from the original 105 specimens from Colorado and Wyoming to identify 16 questionable specimens from low elevation areas in southeastern Wyoming. Data collection and measurement procedures were the same as for the initial 105 specimens described above. We ran the 16 low-elevation Wyoming specimens as a test group to be identified by the DFA generated from the initial specimens using the TESTDATA and TESTLISTERR options for PROC DISCRIM (SAS Institute 1990). We identified the second group of 16 Wyoming specimens by using the second method described above. That is, we ran a single DFA on the mean of the 8 measurements taken for each specimen. We could not use the first method because it would require that we match a particular set of measurements from the low-elevation

Wyoming specimens, with a particular set of measurements from the initial specimens, a subjective process. Also, based on comparisons of the results from both methods we recommend all future DFAs be conducted on the mean of the measurements.

RESULTS

Initial Data Set

All results for the initial data set are for the 105 specimens that showed some tooth wear and had a complete set of cranial measurements required by the DFA. There were no statistical differences in the 12 cranial measurements or toothfold characteristic by sex for either species ($P > 0.370$ sex and $P > 0.163$ for sex×species). Cranial and dental measurements were larger for *Z. p. princeps* skulls compared to *Z. h. preblei* (Table 1). All cranial measurements of *Z. p. princeps* were significantly larger than those of *Z. h. preblei* ($P < 0.002$; Table 2). There were some statistical differences in cranial measurements by observer (Table 3), but these differences were small in relation to the differences between the 2 species (Table 2), and the differences were random (i.e., half of observer 1 measurements were larger than observer 2 and the other half were smaller). Because of the random nature of the differences in measurements between observers, and because differences between observers were small relative to the differences between species, we did not feel this error impinged on the DFA by making it more difficult to delineate between the 2 species.

Cranial measurements of *Z. p. princeps* specimens from southeastern Wyoming were slightly smaller than *Z. p. princeps* from Colorado, although still larger than *Z. h. preblei* (Table 4). Six of the 12 cranial measurements were statistically larger ($P < 0.05$) for Colorado *Z. p. princeps* specimens relative to *Z. p. princeps* from southeastern Wyoming (Table 5).

Evaluation of the presence or absence of the anterior median toothfold characteristic was not consistent within or between observer (Table 6). For example, for the first measurement, 1 observer could judge the toothfold as present, and then for the second measurement the same observer would judge the toothfold absent. Additionally, observer 1 could judge the toothfold as present, while observer 2 judged the toothfold as absent. This lack of consistency resulted in 24% of the specimens having the toothfold recorded as being both present and absent.

Presence of the anterior median toothfold characteristic worked reasonably well for identifying *Z. h. preblei* (Fig. 4); that is, if the mean fold were present, one could be reasonably sure that the specimen was a *Z. h. preblei*, the mean fold was absent for all 71 *Z. p. princeps* specimens. However, although the mean fold (present in > 0.5 of the 4 evaluations) was absent in all DFA-identified *Z. p. princeps*, 14.1% of the evaluations conducted by observer 1 and 2.0% of evaluations by observer 2 resulted in ambiguous results and 1.4% of evaluations by observer 1 resulted in the toothfold being documented as present in *Z. p. princeps* (Table 6). If the mean fold was absent, the specimen could be either a *Z. p. princeps* or a *Z. h. preblei* (Fig. 4

The discriminant function chosen by forward, backward, and stepwise regression all included the same 6 characteristics - lstibw, palbre, pallen, lmtrle, masma, and lm1fold (See Appendix II for key to abbreviations). We present box plots of each cranial and dental measurement used in the DFA, by species, in Appendix III. We checked whether the covariance matrices were equivalent between the species using Bartlett's test in PROC DISCRIM (SAS Institute 1990). Because the null hypothesis of equal covariance was rejected ($P < 0.0001$), we ran the DFA using a quadratic identification rule (Johnson and Wichern 1992, SAS Institute 1990) so that covariances were estimated separately for each species.

The estimated error rate is the proportion of specimens that are not reassigned to their species identification on the museum tag (Johnson and Wichern 1992). Thus, a 0.060 estimated error rate for *Z. p. princeps* indicates that 6.0% of the specimens labeled as *Z. p. princeps* on their museum tags were reidentified as *Z. h. preblei* by the discriminant function. We refer to the estimated error rate as the reidentification rate.

For the first approach in which a separate DFA was run on each set of measurements, the reidentification rate was 3.0% for *Z. p. princeps* specimens and 11.4% for *Z. h. preblei*. The overall reidentification rate for both species was 5.8%. There was no statistical difference in the mean reidentification rate between observers for the overall error rate ($P = 0.124$) or for *Z. p. princeps* ($P = 0.763$), but there was a difference for *Z. h. preblei* ($P = 0.026$; Table 7). Using this approach, 5 of the initial 105 specimens were reidentified by DFA; 3 *Z. h. preblei* and 2 *Z. p. princeps* (Appendix IV). Because repeated measurements were taken on each skull, up to 8 DFAs were performed for each specimen (less than 8 DFAs were performed on a specimen if a crucial measurement was missing due to skull damage acquired during this study). Measurement variation within and between observers sometimes resulted in a specimen being reidentified by DFA for 1 set of measurements, but identified in agreement with the museum tag for the remaining sets of measurements. Using the mean posterior probability for each specimen, DFA reidentified 5 of the initial 105 specimens different from their museum tag identification (Appendix IV). However, if each DFA run was considered separately, then an additional 16 specimens were reidentified for 1-3 of their DFA identifications.

For the second approach in which a single DFA was run on mean measurements for each skull, the reidentification rate was 0.0% for *Z. p. princeps* specimens and 5.9% for *Z. h. preblei*. The overall reidentification rate for both species was 1.9%. For this approach, 2 of the initial 105 specimens were reidentified by DFA; both were *Z. h. preblei* that were reidentified as *Z. p. princeps* (Appendix V).

A Discriminant Function for Identifying Specimens

A straightforward method to identify voucher specimens to species is to measure the selected cranial measurements from this study and use these measurements in a linear DF with a decision criterion. Because the covariances were not equal between the species for the initial 105 specimens used to develop a DF, we used a quadratic DF. A quadratic DF does not provide a direct equation that can be used as a decision criterion for identifying a new specimen to species. Instead, the dataset generated by the quadratic DF for the initial 105 specimens should be used to identify voucher specimens. This data set, along with SAS code to perform a DFA on new specimens, will be available on the United States Fish and Wildlife Website. Contact Bruce Rosenlund (303-275-2392) for the specific Website address.

Southeastern Wyoming Specimens

We used mean cranial and dental measurements to classify 15 low-elevation (<2,300 m) southeastern Wyoming specimens plus 1 specimen from 2,500 m (Appendix VI). The DFA estimated mean reidentification rate, 70.0%, for the southeastern Wyoming specimens was much higher than for the initial specimens (Table 8). All reidentifications were from museum tag identifications of *Z. p. princeps* to DFA identifications of *Z. h. preblei*.

DISCUSSION

We undertook this study to determine whether *Z. h. preblei*, a threatened species, could be positively identified from *Z. p. princeps* throughout its current range based on cranial and dental measurements. Cranial and dental measurements have been used previously to identify various *Zapus* species and subspecies (Krutzsch 1954, Hafner et al. 1981). These studies were however, limited in geographic distribution. Krutzsch (1954) examined only 11 specimens of *Z. h. preblei* and Hafner et al. (1981) examined specimens taken from 2 populations of *Z. p. princeps* and *Z. h. preblei* located in close proximity to each other in Colorado. We wanted to confirm that such cranial differences between the 2 species existed over a larger spatial scale, that is, throughout the Colorado Piedmont and Front Range of Colorado and southeastern Wyoming, the documented historical and potentially the current range of *Z. h. preblei*.

Similar to findings by Hafner et al. (1981) and Krutzsch (1954), we found that skulls of *Z. h. preblei* were smaller than those of *Z. p. princeps*. This difference was manifest as a statistically significant difference in the mean of every skull measurement for the initial specimens from Colorado and southeastern Wyoming. Although *Z. p. princeps* skulls were larger, there were some differences in Colorado and southeastern Wyoming *Z. p. princeps* skull sizes. There is an apparent gradation of skull size of *Z. p. princeps* from Colorado to Wyoming, with Wyoming specimens being smaller than those from

Colorado. However, this northward decrease in cranial size in *Z. p. princeps* is not great enough to overlap the significantly smaller skulls of *Z. h. preblei.*

Three of the measurements used in this study were also measured by Krutzsch (1954). Two of the 3 measurements, zygbre and conlen (See Appendix II for measurement descriptions) were reported by Krutszch as smaller than we found, however pallen was reported as larger. Krutzsch (1954) presented 2 sets of mean measurements for *Z. h. preblei*, (n = 2, 1). The mean measurements Krutzsch (1954) presents *for Z. p. princeps* match more closely with those presented in Table 1 and were means from n = 7, 6, 11, 11, and 20. The mean cranial measurements reported by Hafner et al. (1981) were similar to our measurements (Table 1) and are based on n = 16, 2, and 3 *Z. h. preblei* and n = 12, 4, 18, 39, and 14 Z. *p. princeps*. (Note: we were not able to measure the same specimens as Hafner et al. (1981) because the museum holding those specimens was closed for the duration of this study). Thus, we believe the differences between our means and those of Krutzsch (1954) for *Z. h. preblei* may be due to differences in sample size and possibly measuring tools.

We found little variation within or between observers for cranial measurements (Table 3). Thus, if only means and associated variance estimates for cranial measurements were used to describe the specimens, then repeated measurements may not be necessary. For DFA, however, it was helpful to have repeated sets of measurements. Although 1 outlier measurement of a skull characteristic may not dramatically change a mean or 95% CI calculated using the outlier, it may result in an erroneous reidentification of the specimen by DFA. For example, if each individual DFA run on each single set of measurements were considered separately, 21 specimens were reidentified for 1-3 of their DFA identifications. We examined the data for these 21 reidentified specimens; it appeared that measurement error contributed to these DFA reidentifications. Thus, repeated measurements would attenuate measurement errors for single cranial measurements or data recording errors. Much of the time involved in taking any measurements was in the setup, including laying out of specimens randomly and covering their museum tags, relative to the time required to collect repeated measurements. Therefore, it would not decrease efficiency to do repeated measures on all specimens. Furthermore, using DFA on these repeated measurements, either by using the mean of the individual DFA probabilities or conducting a single DFA on the mean of the measurements, yielded identification of the specimen to species with minimal error.

We found the reidentification rate decreased when the mean posterior probability from the individual DFAs was used compared to using a posterior probability from 1 DFA for a single set of measurements, and then decreased still more when the mean of the measurements was run for a single DFA. For example, 5 specimens were reidentified when using the mean DFA posterior probability from DFAs that were run on each set of measurements for each specimen (Appendix

IV). The mean DFA posterior probabilities for these 5 specimens ranged from 0.45 to 0.66, providing ambiguous results. However, only 2 specimens were reidentified when a single DFA was conducted on the mean of the measurements taken on each specimen (Appendix V). The single DFA probabilities from conducting the analysis on the mean measurements for the same 5 specimens reidentified from the first method were 0.007, 0.111, 0.800, 0.996, and 1.000 (Appendix V); resulting in reidentifying only 2 specimens as *Z. p. princeps* with far stronger support. As a check, we compared the individual cranial measurements and toothfold characteristic and found that for both specimens reidentified all measurements were well within those specified for *Z. p. princeps* in Table 1. Lastly, we checked to see if the specimens identified by Krutzsch (1954) as *Z. h. preblei* were also identified as *Z. h. preblei* by the DFA. Three of the 6 Colorado specimens identified by Krutzsch (1954) were also measured for this study (Appendix I catalog numbers 5210, 503, and 1225). All 3 had probabilities of > 0.999 they were *Z. h. preblei*. The remaining 3 specimens Krutzsch (1954) measured were not kept at museums we borrowed from and thus were not measured for this study. We feel the agreement in identification of at least 3 of the specimens identified by Krutzsch (1954) provides additional support that the DFA developed in this study correctly distinguishes *Z. h. preblei* from *Z. p. princeps*.

This study does not support the use of presence/absence of the anterior medial toothfold characteristic as a definitive characteristic distinguishing *Z. p. princeps* from *Z. h. preblei*. We found that although the presence of a toothfold, if identified by multiple observers, lends strong support a specimen is *Z. h. preblei*, the absence of a toothfold does not identify a specimen as *Z. p. princeps*. In addition to absence of toothfold failing to predict species, presence or absence of the toothfold was not a consistent measurement between or within observers. However, from post-hoc evaluation, side-to-side differences in the toothfold characteristic may be a possible explanation for the high variation. The measuring protocol did not require the observers to evaluate both sides for the toothfold; examining both sides may reduce measurement variation in the toothfold characteristic. Tooth wear is another likely source for the variation; we speculate wear attenuates the fold enough to render detection difficult. Klingener (1963) noted that the fold is deepest in *Z. hudsonius* from the eastern US, and that the fold may be slightly shallower in Midwestern samples and worn away with adult use.

Range maps of *Z. h. preblei* include southeastern Wyoming (Clark and Stromberg 1987). Krutzsch (1954) and Hafner et al. (1981) also identify *Z. h. preblei* specimens in Wyoming; both used cranial measurements to identify these specimens. Additionally, Garber (1995) listed 1 other confirmed *Z. h. preblei* specimen and 2 other relatively recent records. However, the delineation of the historical range of *Z. h. preblei* in southeastern Wyoming is based on a small number of specimens. This paucity of *Z. h. preblei* specimens has resulted in much contention about southeastern Wyoming's inclusion in the range of *Z. h. preblei*. To further evaluate if the range of *Z. h. preblei* extends into Wyoming, we used the DFA function generated from the initial specimens to identify specimens from southeastern Wyoming. The DFA reidentification rate was dramatically different for the low-elevation Wyoming specimens. DFA reidentified 7 of 10 specimens from *Z. p. princeps* to *Z. h. preblei*. Additionally, 1 of the 6 recently collected specimens was DFA-identified as *Z. h. preblei*. Thus, a total of 8 of the 16 southeastern Wyoming specimens were identified as *Z. h. preblei*.

This high reidentification rate is disturbing. We checked the data to confirm there were no gross measurement or recording errors. The data for the 8 specimens DFA-identified as *Z. h. preblei* revealed that: (1) all specimens had a toothfold recorded as present at least once, (2) 5 had an unambiguous toothfold (recorded as present all 4 times), and (3) means for most cranial measurements were close to *Z. h. preblei* measurements. It did not appear that outliers or measurement errors influenced the DFA identifications. It is not known how the 10 specimens from KU, collected between 1945-1948, were originally identified (T. Holms, Collection Manager, Kansas University Museum of Natural History, personal communication). It is possible that they were identified using a range map and not by cranial measurements. The 6 recent specimens had not yet been identified. Of the 11 specimens Krutszch (1954) used to describe *Z. h. preblei*, 5 were from Wyoming. Unfortunately, none of these specimens were used for this study as they were not located in the museums we borrowed specimens from. Three of Krutzsch's specimens were, however, located in Albany County at Springhill, 19.2 km north of Laramie Peak at 1890 m elevation, 1 was located at Chugwater, and 1 was located at Cheyenne. A recent specimen from Chugwater was one of the specimens identified by the DFA as *a Z. h. preblei* and the 7 specimens reidentified as *Z. h. preblei* were from Albany County. Therefore, the *Z. h. preblei* identified in this study match well with the distribution of *Z. h. preblei* suggested by Krutszch (1954).

In conclusion we believe *Z. h. preblei* can be differentiated from *Z. p. princeps* by an objective DFA conducted on a series of cranial and dental measurements. We recommend that multiple measurements be taken of each of the cranial and dental measurements to avoid erroneous results due to either measurement error or recording error. The mean of these measurements should then be run through the DF developed in this study to estimate the probability that the specimen represents a *Z. p. princeps* or *Z. h. preblei*. If a reidentification is suggested by the posterior probability, then as a final check the actual measurements should be compared with the mean measurements for both *Z. h. preblei* and *Z. p. princeps* presented in Table 1. If the individual measurements support a similar result the reidentification should be accepted. We also recommend that the presence of the toothfold, if found by multiple observers, lends strong support that the specimen is a *Z. h. preblei*.

We also recommend that additional voucher specimens be collected and identified through the DF developed in this study to further clarify the current distribution *of Z. h. preblei* in Colorado and southeastern Wyoming. Voucher specimens should be handled with extreme care to ensure the skull remains intact so that all cranial measurements needed for the DFA can be made.

ACKNOWLEDGEMENTS

The United States Fish and Wildlife Services provided financial support for this project through the efforts of B. Rosenlund. We thank D. M. Armstrong and C. Meaney for their helpful comments in designing this study. Earlier drafts of this manuscript were also greatly improved by their comments and comments made from reviewers G. C. White and D. M. Armstrong. The Denver Museum of Nature and Science, University of Kansas Museum of Natural History, and the University of Colorado Museum loaned specimens necessary for this study; we especially thank the curators C. Jones (DMNS) and T. Holms (KU) for their assistance. We thank C. Meaney and R. Adams for their diligence in measuring the skulls. We also thank C. Meaney for assistance with thoroughly examining the toothfold characteristic and reasons for its measurement variation. D. Crawford rendered the skull and tooth drawings. The photograph of the *Z. h. preblei* was taken by Alan B. Franklin.

LITERATURE CITED

Armstrong, D. M. 1972. Distribution of mammals in Colorado. Monograph, University of Kansas Museum of Natural History Monograph 3:1-415.

Clark, T. W. and M. R. Stromberg. 1987. Mammals in Wyoming. University of Kansas, Museum of Natural History, Public Education Series No. 10.

Fitzgerald, J. P., C. A. Meaney, and D. M. Armstrong. 1994. Mammals of Colorado. Denver Museum of Natural History, Denver, and University Press of Colorado, Niwot, Colorado.

Garber, C. S. 1995. A status survey for Preble's jumping mouse (*Zapus hudsonius preblei*) in southeastern Wyoming, including the F. E. Warren Air Force Base. Interior Report United States Fish and Wildlife Service, Denver Colorado.

Hafner, D. J., K. E. Petersen, and T. L. Yates. 1981. Evolutionary relationships of jumping mice (genus *Zapus*) of the southwestern United States. Journal of Mammalogy 62:501-512.

Hall, E. R. 1981. The mammals of North America. 2nd ed. John Wiley & Sons, New York 2:601-1181.

Johnson, R. A., and D. W. Wichern. 1992. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, New Jersey, USA.

Klingener, D. 1963. Dental evolution of *Zapus*. Journal of Mammalogy 44:248-260.

Krutzsch, P. H. 1954. North American jumping mice (genus *Zapus*). University of Kansas Publications, Museum of Natural History 7:349-472.

Lance, R. F., M. L. Kennedy, and P. L. Leberg. 2000. Identification bias in discriminant function analyses used to evaluate putatively different taxa. Journal of Mammalogy 81:245-249.

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS® System for Mixed Models. SAS Institute, Cary, North Carolina, USA.

Long, C. A. 1965. The mammals of Wyoming. University of Kansas Publications, Museum of Natural History 14:493-758.

Manly, B. J. 1986. Multivariate statistical methods: A primer. Chapman and Hall, London, United Kingdom.

SAS Institute. 1990. SAS/STAT user's guide, Version 6. Forth edition. Volume 1. SAS Institute, Cary, North Carolina, USA.

United States Fish and Wildlife Service. 1998. Final rule to list Preble's meadow jumping mouse as a threatened species. United States Fish and Wildlife Service Final Report Part 17. Federal Register 63(92): 26517-26530.

Whitaker, J. O., Jr. 1972. *Zapus hudsonius*. Mammalian Species 111:1-7.

TABLE 1.—Mean cranial measurements, standard errors, and 95% confidence intervals for initial sample of *Zapus princeps princeps* (*n* = 71) and *Z. hudsonius preblei* (*n* = 34) specimens collected in Colorado and southeastern Wyoming.

Skull measurement[a]	Species	Mean[b]	SE[c]	Lower 95%CI	Upper 95%CI
zygbre	*Z. p. princeps*	12.22	0.07	12.09	12.35
zygbre	*Z. h. preblei*	11.28	0.09	11.11	11.45
conlen	*Z. p. princeps*	21.89	0.10	21.69	22.10
conlen	*Z. h. preblei*	20.63	0.14	20.35	20.91
lstiob	*Z. p. princeps*	4.48	0.02	4.44	4.52
lstiob	*Z. h. preblei*	4.26	0.03	4.21	4.32
lstibw	*Z. p. princeps*	2.15	0.02	2.12	2.18
lstibw	*Z. h. preblei*	1.79	0.02	1.75	1.84
masma	*Z. p. princeps*	9.23	0.04	9.15	9.31
masma	*Z. h. preblei*	8.81	0.06	8.70	8.92
palbre	*Z. p. princeps*	3.79	0.02	3.75	3.82
palbre	*Z. h. preblei*	3.36	0.03	3.31	3.42
pallen	*Z. p. princeps*	9.14	0.04	9.06	9.21
pallen	*Z. h. preblei*	8.38	0.06	8.27	8.49
umtrlen	*Z. p. princeps*	4.13	0.02	4.10	4.17
umtrlen	*Z. h. preblei*	3.90	0.03	3.85	3.95
lmtrle	*Z. p. princeps*	4.10	0.02	4.06	4.13
lmtrle	*Z. h. preblei*	3.77	0.03	3.72	3.83
iflen	*Z. p. princeps*	4.63	0.03	4.58	4.69
iflen	*Z. h. preblei*	4.22	0.04	4.14	4.31
ifwid	*Z. p. princeps*	2.21	0.02	2.18	2.24
ifwid	*Z. h. preblei*	2.02	0.02	1.98	2.07
pm4wid	*Z. p. princeps*	0.55	0.01	0.54	0.56
pm4wid	*Z. h. preblei*	0.52	0.01	0.50	0.54

[a] See Appendix II for a key to abbreviations.
[b] Mean based on least square means.
[c] Variance based on Type III sum-of-squares with degrees of freedom adjusted for repeated measurements.

TABLE 2.—Differences in cranial measurements between *Zapus princeps princeps* (n = 71) and *Z. hudsonius preblei* (n = 34) for initial sample of specimens collected in Colorado and southeastern Wyoming.

Skull measurement[a]	Difference[b,c]	SE[d]	Lower 95%CI	Upper 95%CI	F	P
zygbre	0.94	0.11	0.73	1.16	75.62	<.0001
conlen	1.27	0.17	0.92	1.61	53.07	<.0001
lstiob	0.21	0.04	0.14	0.28	35.84	<.0001
lstibw	0.36	0.03	0.30	0.41	163.71	<.0001
masma	0.42	0.07	0.28	0.56	37.48	<.0001
palbre	0.42	0.04	0.35	0.49	144.50	<.0001
pallen	0.75	0.07	0.62	0.88	126.70	<.0001
umtrlen	0.23	0.03	0.17	0.29	55.82	<.0001
lmtrle	0.32	0.03	0.26	0.39	105.70	<.0001
iflen	0.41	0.05	0.31	0.51	65.95	<.0001
ifwid	0.19	0.03	0.13	0.24	43.33	<.0001
pm4wid	0.03	0.01	0.01	0.05	10.23	0.0018

[a] See Appendix II for a key to abbreviations.
[b] *Z. p. princeps* minus *Z. h. preblei*
[c] Difference based on least square means.
[d] Variance based on Type III sum-of-squares with degrees of freedom adjusted for repeated measurements.

TABLE 3.—Differences in cranial measurements between observers for initial sample of *Zapus princeps princeps* (*n* = 71) and *Z. hudsonius preblei* (*n* = 34) specimens collected in Colorado and southeastern Wyoming.

Skull measure-ment[a]	Species	Dif-ference[b,c]	SE[d]	Lower 95%CI	Upper 95%CI	*F*	*P*
zygbre	*Z. p. princeps*	-0.09	0.02	-0.12	-0.06	32.11	<.0001
zygbre	*Z. h. preblei*	-0.10	0.02	-0.14	-0.06	21.95	<.0001
conlen	*Z. p. princeps*	-0.08	0.02	-0.11	-0.05	20.30	<.0001
conlen	*Z. h. preblei*	-0.12	0.03	-0.19	-0.06	13.25	0.000
lstiob	*Z. p. princeps*	-0.03	0.01	-0.04	-0.01	18.16	<.0001
lstiob	*Z. h. preblei*	-0.01	0.01	-0.03	0.01	0.68	0.411
lstibw	*Z. p. princeps*	0.11	0.02	0.08	0.14	51.32	<.0001
lstibw	*Z. h. preblei*	0.00	0.02	-0.04	0.03	0.05	0.820
masma	*Z. p. princeps*	0.02	0.02	-0.03	0.06	0.38	0.539
masma	*Z. h. preblei*	0.03	0.04	-0.05	0.11	0.59	0.443
palbre	*Z. p. princeps*	-0.08	0.01	-0.1	-0.06	72.73	<.0001
palbre	*Z. h. preblei*	-0.05	0.02	-0.08	-0.02	12.08	0.001
pallen	*Z. p. princeps*	-0.17	0.01	-0.19	-0.15	222.90	<.0001
pallen	*Z. h. preblei*	-0.16	0.02	-0.20	-0.12	62.74	<.0001
umtrlen	*Z. p. princeps*	0.20	0.01	0.18	0.22	419.50	<.0001
umtrlen	*Z. h. preblei*	0.18	0.02	0.14	0.21	101.80	<.0001
lmtrle	*Z. p. princeps*	0.17	0.01	0.14	0.20	172.20	<.0001
lmtrle	*Z. h. preblei*	0.12	0.02	0.09	0.15	57.23	<.0001
iflen	*Z. p. princeps*	0.04	0.01	0.02	0.07	14.36	0.000
iflen	*Z. h. preblei*	0.02	0.01	-0.01	0.04	1.14	0.286
ifwid	*Z. p. princeps*	0.06	0.01	0.05	0.07	110.00	<.0001
ifwid	*Z. h. preblei*	0.00	0.01	-0.02	0.02	0.05	0.832
pm4wid	*Z. p. princeps*	-0.04	0.00	-0.05	-0.04	106.10	<.0001
pm4wid	*Z. h. preblei*	-0.08	0.01	-0.09	-0.06	76.75	<.0001

[a] See Appendix II for a key to abbreviations.

[b] Measurements from observer 1 minus observer 2.

[c] Difference based on least square means.

[d] Variance based on Type III sum-of-squares with degrees of freedom adjusted for repeated measurements.

TABLE 4.—Mean cranial measurements and 95%CI's for initial sample of *Zapus princeps princeps* from Colorado (*n* = 53), *Z. p. princeps* from southeastern Wyoming (*n* = 18), and *Z. hudsonius preblei* (*n* = 34); all *Z. h. preblei* specimens were from Colorado.

Skull measurement[a]	State	Species	Mean[b]	SE[c]	Lower 95%CI	Upper 95%CI
zygbre	CO	*Z. p. princeps*	12.32	0.07	12.18	12.46
zygbre	WY	*Z. p. princeps*	12.00	0.13	11.75	12.24
zygbre	CO	*Z. h. preblei*	11.27	0.08	11.11	11.44
conlen	CO	*Z. p. princeps*	21.99	0.12	21.77	22.22
conlen	WY	*Z. p. princeps*	21.63	0.20	21.23	22.02
conlen	CO	*Z. h. preblei*	20.64	0.14	20.37	20.91
lstiob	CO	*Z. p. princeps*	4.51	0.02	4.46	4.55
lstiob	WY	*Z. p. princeps*	4.38	0.04	4.31	4.46
lstiob	CO	*Z. h. preblei*	4.26	0.03	4.21	4.32
lstibw	CO	*Z. p. princeps*	2.17	0.02	2.13	2.20
lstibw	WY	*Z. p. princeps*	2.11	0.03	2.05	2.17
lstibw	CO	*Z. h. preblei*	1.79	0.02	1.75	1.84
masma	CO	*Z. p. princeps*	9.31	0.04	9.23	9.39
masma	WY	*Z. p. princeps*	9.00	0.07	8.86	9.14
masma	CO	*Z. h. preblei*	8.82	0.05	8.72	8.93
palbre	CO	*Z. p. princeps*	3.80	0.02	3.76	3.85
palbre	WY	*Z. p. princeps*	3.73	0.04	3.66	3.81
palbre	CO	*Z. h. preblei*	3.36	0.03	3.31	3.42
pallen	CO	*Z. p. princeps*	9.18	0.04	9.10	9.26
pallen	WY	*Z. p. princeps*	9.02	0.07	8.87	9.16
pallen	CO	*Z. h. preblei*	8.38	0.05	8.28	8.49
umtrlen	CO	*Z. p. princeps*	4.16	0.02	4.12	4.20
umtrlen	WY	*Z. p. princeps*	4.04	0.03	3.98	4.11
umtrlen	CO	*Z. h. preblei*	3.90	0.02	3.86	3.95
lmtrle	CO	*Z. p. princeps*	4.15	0.02	4.11	4.18
lmtrle	WY	*Z. p. princeps*	3.96	0.03	3.90	4.02
lmtrle	CO	*Z. h. preblei*	3.78	0.02	3.73	3.82
iflen	CO	*Z. p. princeps*	4.63	0.03	4.57	4.70
iflen	WY	*Z. p. princeps*	4.63	0.06	4.52	4.74
iflen	CO	*Z. h. preblei*	4.23	0.04	4.15	4.31
ifwid	CO	*Z. p. princeps*	2.21	0.02	2.18	2.25
ifwid	WY	*Z. p. princeps*	2.21	0.03	2.14	2.27
ifwid	CO	*Z. h. preblei*	2.03	0.02	1.98	2.07
pm4wid	CO	*Z. p. princeps*	0.54	0.01	0.53	0.56
pm4wid	WY	*Z. p. princeps*	0.58	0.01	0.56	0.60
pm4wid	CO	*Z. h. preblei*	0.52	0.01	0.50	0.53

[a] See Appendix II for a key to abbreviations.

[b] Mean based on least square means.

[c] Variance based on Type III sum-of-squares with degrees of freedom adjusted for repeated measurements.

TABLE 5.—Differences in cranial measurements for initial sample of *Zapus princeps princeps* specimens collected in Colorado (n = 53) and southeastern Wyoming(n = 18).

Skull measurement[a]	Difference[b,c]	SE[d]	Lower 95%CI	Upper 95%CI	F	P
zygbre	0.32	0.14	0.04	0.61	5.01	0.030
conlen	0.37	0.23	-0.09	0.82	2.52	0.110
lstiob	0.12	0.04	0.04	0.21	7.62	0.006
lstibw	0.06	0.04	-0.01	0.13	2.66	0.103
Masma	0.31	0.08	0.14	0.47	13.61	0.000
palbre	0.07	0.04	-0.01	0.16	2.79	0.095
pallen	0.16	0.08	0.00	0.33	3.66	0.056
umtrlen	0.12	0.04	0.04	0.19	9.44	0.002
lmtrle	0.19	0.04	0.11	0.26	25.87	<.0001
iflen	0.01	0.06	-0.12	0.13	0.01	0.919
ifwid	0.01	0.04	-0.07	0.08	0.02	0.887
pm4wid	-0.04	0.01	-0.06	-0.01	7.92	0.005

[a] See Appendix II for a key to abbreviations.

[b] Colorado minus Wyoming.

[c] Difference based on least square means.

[d] Variance based on Type III sum-of-squares with degrees of freedom adjusted for repeated measurements.

TABLE 6.—Percentage of times the anterior medial toothfold was recorded as present every time, absent every time, or ambiguous for the initial 105 specimens. Ambiguous measurement resulted when the toothfold was recorded as present during 1 measurement session, and then absent during another measurement session.

	Ambiguous (%)	Present (%)	Absent (%)
Z. p. princeps[a]			
Observer 1	14.1	1.4	84.5
Observer 2	2.0	0.0	97.2
Z. h. preblei[b]			
Observer 1	26.5	47.1	26.5
Observer 2	8.8	52.9	38.2

[a] Toothfold should be absent.
[b] Toothfold should be present.

TABLE 7.—Discriminant function analysis reidentification rates[a] for the initial 105 *Zapus princeps princeps* and *Z. hudsonius preblei* specimens from Colorado and southeastern Wyoming[b].

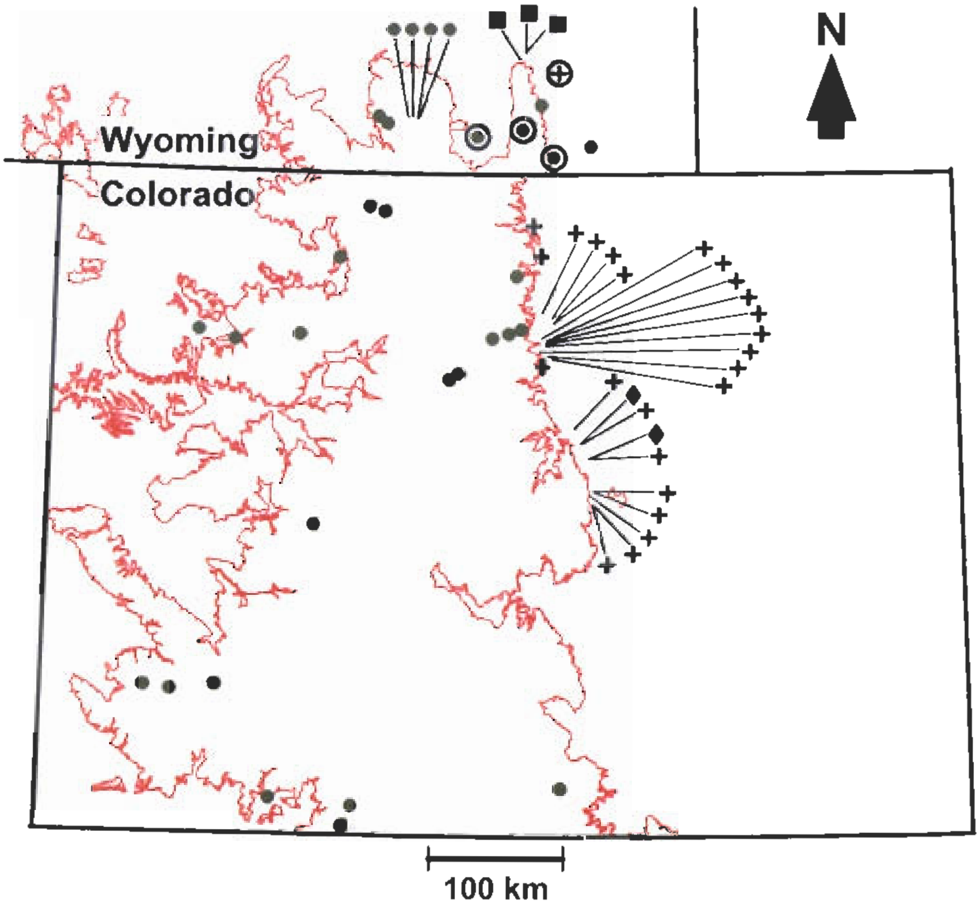
		Reidentification rate		
Observer	Measurement	*Z. p. princeps*	*Z. h. preblei*	Overall
1	1	0.055	0.094	0.069
1	2	0.055	0.094	0.069
1	3	0.000	0.069	0.024
1	4	0.000	0.000	0.000
2	1	0.044	0.182	0.089
2	2	0.029	0.182	0.078
2	3	0.029	0.206	0.087
2	4	0.029	0.088	0.048
	Mean	0.030	0.114	0.058
	SE	0.008	0.025	0.011

[a] The reidentification rate is the number of specimens DFA identified as different from the museum tag.
[b] The measurements used in DFA were lstibw, palbre, pallen, lmtrlen, masma, and lm1fold (see Appendix II for a key to abbreviations).

TABLE 8.—Specimen museum tag identification, discriminant function[a] analysis identification, and the associated posterior probability that a specimen was a *Zapus princeps princeps* for specimens from southeastern Wyoming. These specimens were run as a test group based on the DFA developed by the initial 105 specimens. A single DFA was done on mean measurements of these 16 specimens.

Cat. number	Coll. Date	Tag identification	DFA identification	DFA posterior *P*	Elev. (m)
1827	20-Jul-99	none[b]	*Z. h. preblei*	0.000	1,835
27938	6-Sep-48	*Z. p. princeps*	*Z. p. princeps*	1.000	1,957
27939	7-Sep-48	*Z. p. princeps*	*Z. h. preblei*	0.000	1,957
27940	7-Sep-48	*Z. p. princeps*	*Z. h. preblei*	0.000	1,957
27941	7-Sep-48	*Z. p. princeps*	*Z. h. preblei*	0.000	1,957
27942	7-Sep-48	*Z. p. princeps*	*Z. h. preblei*	0.000	1,957
27943	7-Sep-48	*Z. p. princeps*	*Z. h. preblei*	0.000	1,957
27944	8-Sep-48	*Z. p. princeps*	*Z. h. preblei*	0.000	2,041
27671	5-Aug-48	*Z. p. princeps*	*Z. h. preblei*	0.008	2,060
1822	14-Aug-00	none	*Z. p. princeps*	1.000	2,195
1823	13-Aug-00	none	*Z. p. princeps*	1.000	2,195
1824	13-Aug-00	none	*Z. p. princeps*	1.000	2,195
15856	17-Jul-45	*Z. p. princeps*	*Z. p. princeps*	1.000	2,195
15857	17-Jul-45	*Z. p. princeps*	*Z. p. princeps*	1.000	2,195
1826	12-Jul-00	none	*Z. p. princeps*	1.000	2,256
1825	30-Jul-99	none	*Z. p. princeps*	1.000	2,499

[a] The measurements used in DFA were lstibw, palbre, pallen, lmtrlen, masma, and lm1fold (see Appendix II for a key to abbreviations).
[b] None" indicates that the specimen had not yet been identified by a mammalogist.



+ Specimens identified by both museum records and DFA as *Z. h. preblei*

● Specimens identified by both museum records and DFA as *Z. p. princeps*

◆ Specimens identified by museum records as *Z. h. preblei*, but by DFA as *Z. p. princeps*

■ Specimens identified by museum records as *Z. p. princeps*, but by DFA as *Z. h. preblei*

A circle around either + or ● indicates specimens identified only by DFA

Elevations >2,400 m

FIGURE 1. Locations of *Zapus hudsonius preblei* and *Z. princeps princeps* specimens in Colorado and Wyoming; species identification as determined by museum identification and by discriminant function analysis (DFA) on means of repeated measurements. Ten additional specimens are not indicated on map because they had inadequate collection coordinates or locality descriptions. One symbol may represent several specimens collected at the same location. See Appendix I for a detailed description of specimen locations.

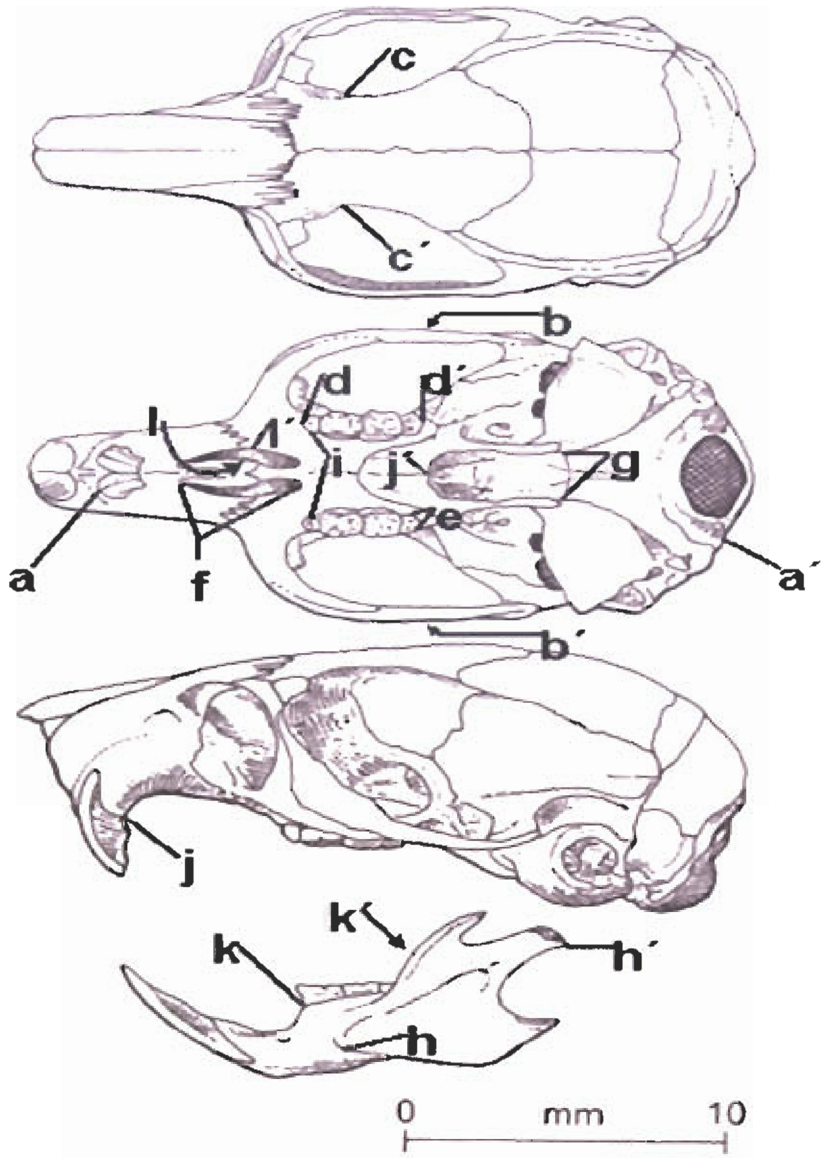


FIGURE 2. Three views of a *Zapus* skull to show points between which measurements of the skull were taken (drawing modified from Whitaker, 1972). Letters refer to the following cranial measurement: (a - a') condylobasal length, (b - b') zygomatic breadth, (c - c') least interorbital breadth, (d - d') upper toothrow length, (e) P^4 width, (f) incisive foramina length, (g) least interbullar width, (h - h') masseter moment arm, (i) palatal breadth at P^4, (j - j') palatal length, (k - k') lower molar toothrow length, and (l - l') incisive foramina width.

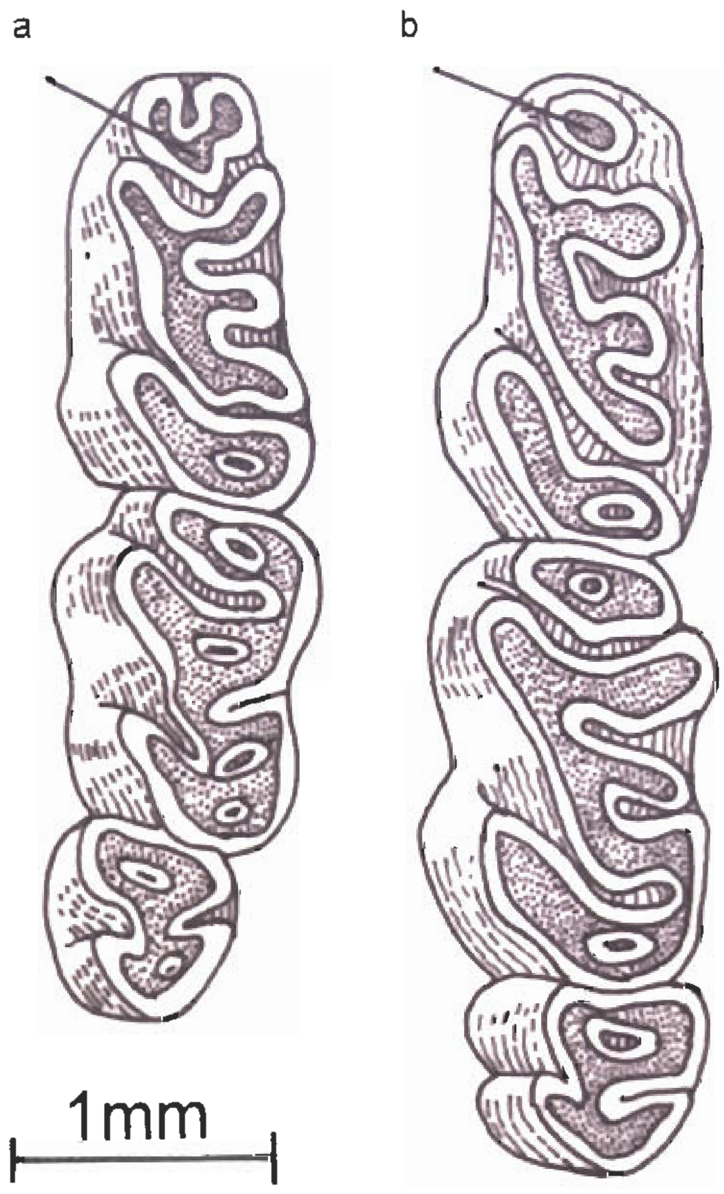


FIGURE 3. Lower dentition of (a) *Zapus hudsonius preblei* and (b) *Z. princeps princeps* showing the anterior medial toothfold characteristic (drawing modified from Klingener, 1963).

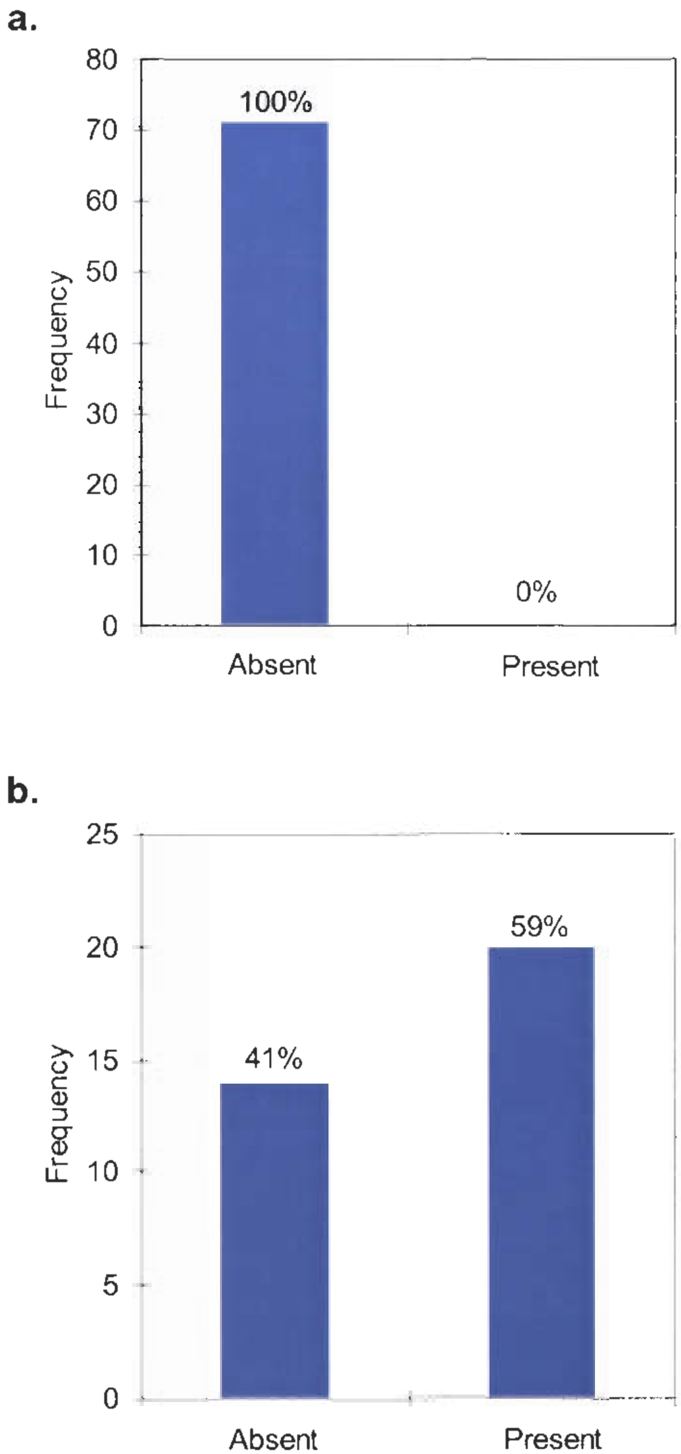


FIGURE 4. Histogram of the presence or absence of the anterior median toothfold characteristic for (a) *Zapus princeps princeps* and (b) *Z. hudsonius preblei*.

APPENDIX I

Specimens Examined

All specimens were borrowed from Denver Museum of Nature and Science, University of Colorado Museum, and University of Kansas Museum of Natural History. Numbers in parentheses refer to the museum collection catalogue.

Initial Specimens.—

Denver Museum of Nature and Science

Zapus hudsonius preblei—Colorado: Boulder Co., Niwot (2394); 3 mi NW Niwot (2971); S Boulder Creek (9314); S. Boulder Creek, 400 m S Baseline Rd. (9564, 9578); 0.25 mi. S Saint Vrain Rd. on U.S. 36 (9204, 9205); UTM coordinates 480280E, 4423640N Zone 13 (9843); Douglas Co., Colorado Division of Wildlife property, Woodhouse Ranch (9570, 9573, 9875, 9876, 9878); Maytag Property (9576, 9577); Pine Cliff (9853, 9857); El Paso Co., Beaver Creek, 2 mi. SW Monument (9579); Air Force Academy (9315); Dirty Woman Creek (9313, 9562, 9565); Gilpin Co., Ralston Creek (9312); Jefferson Co., 1.25 mi W Semper (6634); Rocky Flats (9203); Larimer Co., Young's Gulch (9561); Little Bear Gulch (9568).

Zapus princeps princeps—Colorado: Archuleta Co., Navaho River (1229, 1484, 1486, 1488, 1489); Devils Creek (5575, 5576); Boulder Co., no location (3354); Larimer Co., Big Thompson River in Estes Park (9560); no location (1053). Las Animas Co., Purgatory Campground, San Isabel National Forest (7914, 7915, 7917-7919); Routt Co., Stillwater Reservoir (4970, 4971). Wyoming: Laramie Co., Warren Air Force Base (9316).

University of Colorado at Boulder

Zapus hudsonius preblei—Colorado: Boulder Co., 5 mi E Boulder (503); south of Boulder at intersection of Baseline Rd and Turnpike (1225); 8.5 mi N, 3.25 mi E Boulder (5210); 0.5 mi ESE of Eldorado Springs (17001); Van Vleet Open Space, Cherryvale at S. Boulder Rd, Boulder (17733); El Paso Co., U.S. Air Force Academy, Monument Creek, 0.25 mi S sewage treatment plant (17002); Jefferson Co., Rocky Flats, Woman Creek, 0.5 mi W Indiana Rd (17196).

Zapus princeps princeps—Colorado: Boulder Co., Science Lodge, 3 mi SSW Ward (5270, 5273, 14226, 14227); 1 mi E Lakewood (5271, 5272); Pennsylvania Gulch, 0.25 mi SW Sunset (5105); Forth-of-July Campground, 10 mi NW Nederland (5968-5970); Dolores Co., 12 mi N Rico (5397); Grand Co., Lone Cone Peak (13741), Steelman Creek (14365–14368); McQueary Creek (14370, 14372–14375); Grand Co., Ptarmigan Camp (14913, 14915); Gunnison Co., Crested Butte, Deckers' Ranch (10920), Jackson Co., Lake John, Brand's Ranch (10916); Mt Zirkel, Ute Pass Trail (10917, 10918); Ouray Co., Red Mountain Pass (13737, 13739, 13740, 13742, 13744); Routt Co., Steamboat Springs (10912), Rio Blanco Co., Meeker (10913), Big Beaver Creek (10914, 10915).

University of Kansas

Zapus princeps princeps—Wyoming: Albany Co., 3 mi ESE Brown's Peak (17575–17580, 17581, 17582); Albany Co., 2 mi S Brown's Peak (17573); Nash's Fork (91354); Carbon Co., 14 mi E, 6 mi S Saratoga (26500); 18 mi E, 8 mi N Encampment (26566); Lake Marie, Medicine Bow National Forest (27666-27670).

Southeastern "low-elevation" Wyoming Specimens.—

Denver Museum of Nature and Science

Zapus sp.—Wyoming: Albany Co., between Snowy Range and Laramie (1822-1824); Laramie Co., South Lodgepole Creek, Medicine Bow National Forest

(1825); I80, Harriman Road exit, Lone Tree Creek (1826); Chugwater Creek (1827).

University of Kansas

Zapus princeps princeps—Wyoming: Albany Co., 30 mi N, 10 mi E Laramie (27671); 29 mi N, 8.75 mi E Laramie (27938-27943); 26.75 mi N, 6.5 mi E Laramie (27944); Carbon Co., 10 mi N, 12 mi E Encampment (26505, 26506), Laramie Co., 1 mi N, 5 mi W Horse Creek Post Office (15856-15858).

APPENDIX II

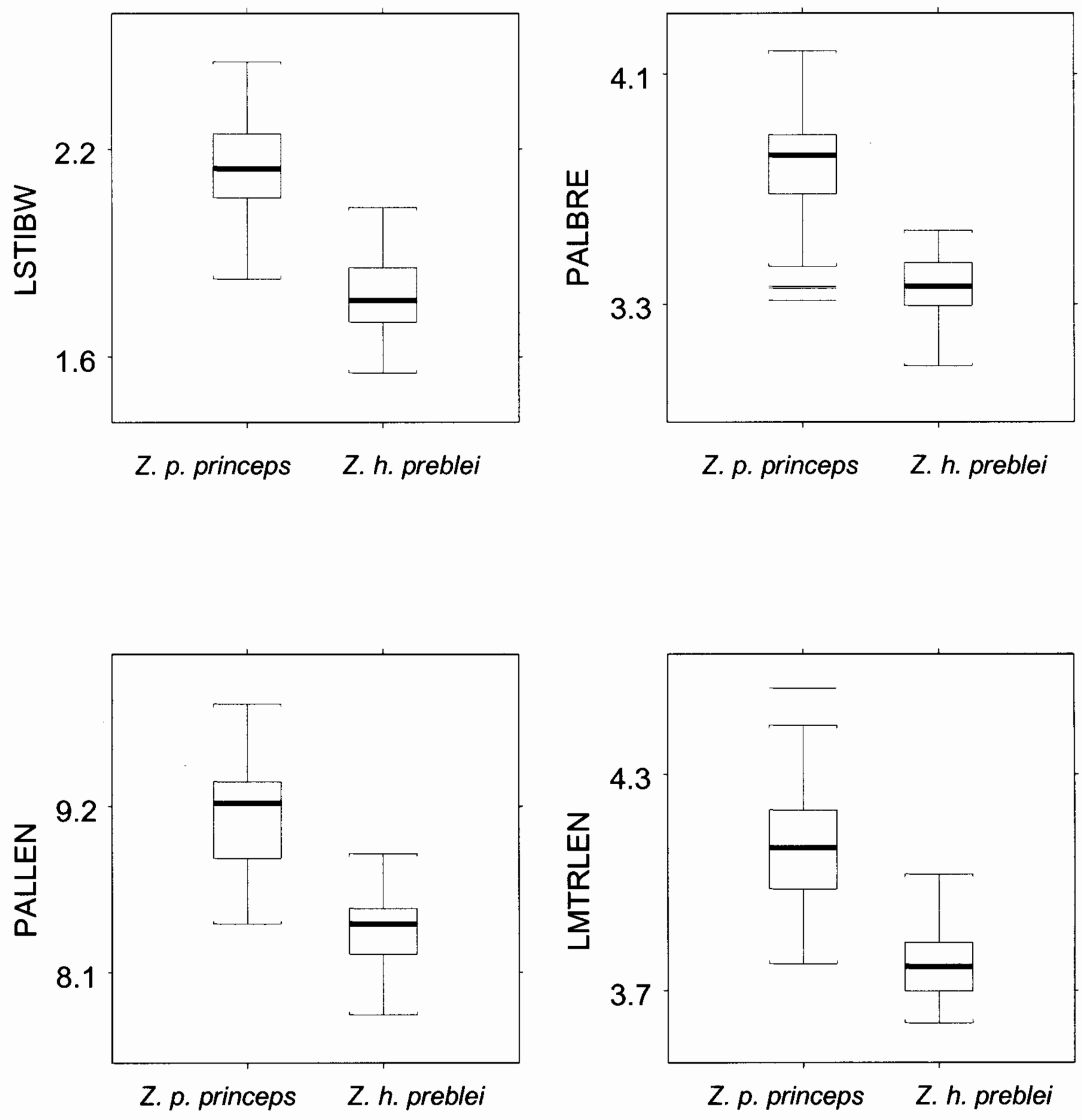
Description of Characters

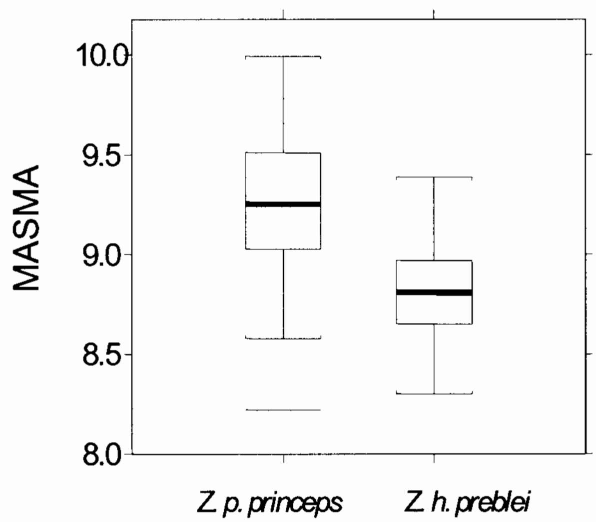
Descriptions of morphometric measurements taken in this study are provided below. Letters refer to the character depicted in Fig. 2. The abbreviations in parentheses are used in Tables 1-5.

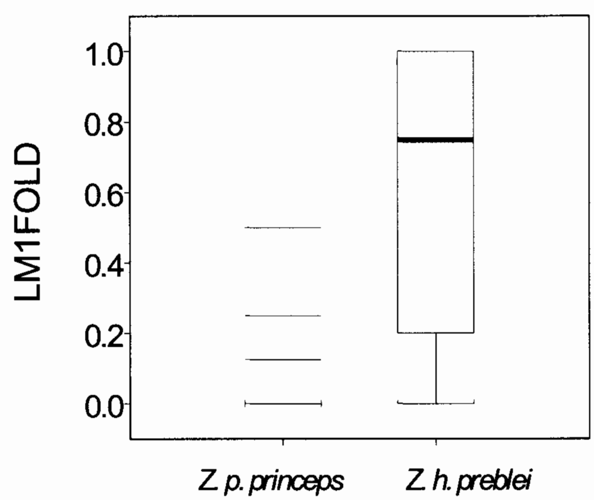
a. Condylobasal Length (conlen): From the anterior edge of the premaxillae to the posteriormost projection of the occipital condyles: a to a′.
b. Zygomatic Breadth (zygbre): Greatest distance between the outer margins of the zygomatic arches: b to b′.
c. Least Interorbital Breadth (lstiob): Least distance, measured dorsally, between the orbits: c to c′.
d. Upper Toothrow Length (umtrlen): Length of toothrow from anterior edge of first alveoli to the posterior edge of last alveoli (includes fourth premolar and three molars): d to d′.
e. P^4 Width (pm4wid): Width of fourth premolar: e.
f. Incisive Foramina Length (iflen): Interior measurement from anterior to posterior edge of incisive foramina: f.
g. Least Interbullar Width (lstibw): Least distance ventrally between the bullae, measured at the basisphenoid/basioccipital suture: g.
h. Masseter Moment Arm (masma): Articular condyle to anterior-most scar of the masseter: h to h′.
i. Palatal Breadth at P^4 (palbre): Breadth of the palate measured at P^4, from medial edge of alveolus to medial edge of alveolus: i.
j. Palatal Length (pallen): From posterior edge of the alveoli to the anteriormost point on the posterior edge of the palate: j to j′.
k. Lower Molar Toothrow Length (lmtrlen): Length of toothrow from anterior edge of first alveolus to the posterior edge of last alveolus: k to k′ (k′ not actually visible; arrow points to region).
l. Incisive Foramina Width (ifwid): Interior measurement from lateral edge to lateral edge of foramiena: l to l′.

Appendix III

Distribution of mean cranial and dental measurements used in DFA Box plot of the distributions of mean measurements for the 105 initial specimens; that is, the box plots for *Zapus princeps princeps* represent mean measurements for 71 specimens, and the box plots for *Z. hudsonius preblei* represent the mean measurement for 34 specimens. See Appendix II for a key to abbreviations of cranial measurements.




MASMA
10.0
9.5
9.0
8.5
8.0
Z. p. princeps
Z. h. preblei


LM1FOLD
1.0
0.8
0.6
0.4
0.2
0.0
Z. p. princeps
Z. h. preblei

APPENDIX IV

Specimen museum tag identification, discriminant function[a] analysis identification, and the associated posterior probability that a specimen was a *Zapus princeps princeps* for the initial sample of 105 *Zapus* specimens from Colorado and southeastern Wyoming. DFA was run separately for each set of measurements and then posterior probabilities averaged.

Cat. Number	N	Coll. Date	Tag identification	DFA identification	*P*	Elev. (m)	State	Museum
5105	4	17-Aug-46	*Z. p. princeps*	*Z. p. princeps*	1.000	1,506	CO	CU
2971	8	3-Sep-35	*Z. h. preblei*	*Z. h. preblei*	0.001	1,527	CO	DM
2394	8	7-Jan-30	*Z. h. preblei*	*Z. h. preblei*	0.193	1,553	CO	DM
5210	4	3-Aug-47	*Z. h. preblei*	*Z. h. preblei*	0.000	1,554	CO	CU
503	8	5-May-08	*Z. h. preblei*	*Z. h. preblei*	0.063	1,609	CO	CU
9564	8	13-Aug-98	*Z. h. preblei*	*Z. h. preblei*	0.001	1,615	CO	DM
9578	8	17-Jul-97	*Z. h. preblei*	*Z. h. preblei*	0.001	1,625	CO	DM
17733	8	14-Sep-91	*Z. h. preblei*	*Z. h. preblei*	0.020	1,625	CO	CU
1225	2	30-May-14	*Z. h. preblei*	*Z. h. preblei*	0.000	1,646	CO	CU
9314	8	16-Jul-97	*Z. h. preblei*	*Z. h. preblei*	0.131	1,646	CO	DM
9843	8	10-Jul-98	*Z. h. preblei*	*Z. h. preblei*	0.000	1,675	CO	DM
6634	6	17-Oct-09	*Z. h. preblei*	*Z. h. preblei*	0.358	1,676	CO	DM
9204	8	28-Aug-97	*Z. h. preblei*	*Z. h. preblei*	0.001	1,703	CO	DM
9205	8	26-Aug-97	*Z. h. preblei*	*Z. h. preblei*	0.035	1,703	CO	DM
9570[b]	**8**	**5-Jun-98**	***Z. h. preblei***	***Z. p. princeps***	**0.522**	**1,730**	**CO**	**DM**
9573	8	6-Aug-98	*Z. h. preblei*	*Z. h. preblei*	0.137	1,730	CO	DM
9875	8	16-Jun-99	*Z. h. preblei*	*Z. h. preblei*	0.126	1,730	CO	DM
9876	8	11-Sep-99	*Z. h. preblei*	*Z. h. preblei*	0.036	1,730	CO	DM
9878	8	3-Oct-99	*Z. h. preblei*	*Z. h. preblei*	0.056	1,730	CO	DM
17196	8	6-Aug-88	*Z. h. preblei*	*Z. h. preblei*	0.002	1,737	CO	CU
9561	8	13-Jul-98	*Z. h. preblei*	*Z. h. preblei*	0.281	1,780	CO	DM
9853	8	15-Sep-99	*Z. h. preblei*	*Z. h. preblei*	0.000	1,796	CO	DM
9857[b]	**8**	**26-Aug-99**	***Z. h. preblei***	***Z. p. princeps***	**0.663**	**1,796**	**CO**	**DM**
9203	6	31-Aug-95	*Z. h. preblei*	*Z. h. preblei*	0.000	1,814	CO	DM
17001	8	6-Jul-89	*Z. h. preblei*	*Z. h. preblei*	0.240	1,829	CO	CU
9316	8	2-Aug-96	*Z. p. princeps*	*Z. p. princeps*	1.000	1,878	WY	DM
10913	8	6-Jul-03	*Z. p. princeps*	*Z. p. princeps*	1.000	1,890	CO	CU
9312	8	16-Jul-97	*Z. h. preblei*	*Z. h. preblei*	0.000	1,951	CO	DM
9576	8	8-Jun-98	*Z. h. preblei*	*Z. h. preblei*	0.466	1,960	CO	DM

APPENDIX IV.--Continued.

Cat. Number	N	Coll. Date	Tag identification	DFA identification	*P*	Elev. (m)	State	Museum
9577	8	10-Sep-98	*Z. h. preblei*	*Z. h. preblei*	0.279	1,960	CO	DM
17002	8	7-Sep-90	*Z. h. preblei*	*Z. h. preblei*	0.000	1,963	CO	CU
5575	8	23-Jul-47	*Z. p. princeps*	*Z. p. princeps*	1.000	2,012	CO	DM
5576	8	23-Jul-47	*Z. p. princeps*	*Z. p. princeps*	0.997	2.012	CO	DM
9568	6	8-Aug-98	*Z. h. preblei*	*Z. h. preblei*	0.136	2,023	CO	DM
10912	6	4-Jun-03	*Z. p. princeps*	*Z. p. princeps*	0.990	2,057	CO	CU
10914	8	10-Jul-03	*Z. p. princeps*	*Z. p. princeps*	1.000	2,073	CO	CU
10915	4	10-Jul-03	*Z. p. princeps*	*Z. p. princeps*	0.998	2,073	CO	CU
9315	8	24-Aug-97	*Z. h. preblei*	*Z. h. preblei*	0.116	2,103	CO	DM
9313	8	12-Sep-97	*Z. h. preblei*	*Z. h. preblei*	0.000	2,132	CO	DM
3354	8	31-Jul-38	*Z. p. princeps*	*Z. p. princeps*	1.000	2,133	CO	DM
9562[b]	**8**	**30-Aug-98**	***Z. h. preblei***	***Z. p. princeps***	**0.531**	**2,133**	**CO**	**DM**
9565	8	12-Jul-98	*Z. h. preblei*	*Z. h. preblei*	0.001	2,133	CO	DM
9579	8	24-Jul-97	*Z. h. preblei*	*Z. h. preblei*	0.000	2,134	CO	DM
1484	8	18-Aug-14	*Z. p. princeps*	*Z. p. princeps*	0.752	2,256	CO	DM
1486	8	2-Sep-14	*Z. p. princeps*	*Z. p. princeps*	1.000	2,256	CO	DM
1488	8	27-Sep-14	*Z. p. princeps*	*Z. p. princeps*	1.000	2,256	CO	DM
1489	8	24-Sep-14	*Z. p. princeps*	*Z. p. princeps*	1.000	2,256	CO	DM
9560	8	31-Oct-98	*Z. p. princeps*	*Z. p. princeps*	1.000	2,377	CO	DM
5271	6	7-Aug-45	*Z. p. princeps*	*Z. p. princeps*	1.000	2,469	CO	CU
5272	8	7-Aug-45	*Z. p. princeps*	*Z. p. princeps*	1.000	2,469	CO	CU
10916	4	7-Jul-01	*Z. p. princeps*	*Z. p. princeps*	1.000	2,515	CO	CU
1229	4	13-Aug-15	*Z. p. princeps*	*Z. p. princeps*	0.640	2,560	CO	DM
7914	8	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
7915	8	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
7917	8	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
7918	8	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
7919	8	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
26500	8	22-Jun-48	*Z. p. princeps*	*Z. p. princeps*	0.997	2,682	WY	KU
14913	7	1-Aug-71	*Z. p. princeps*	*Z. p. princeps*	0.957	2,701	CO	CU
14915	8	2-Aug-71	*Z. p. princeps*	*Z. p. princeps*	1.000	2,701	CO	CU
10920	8	1-Jul-03	*Z. p. princeps*	*Z. p. princeps*	0.998	2,707	CO	CU
26566	8	10-Jul-48	*Z. p. princeps*	*Z. p. princeps*	1.000	2,712	WY	KU

APPENDIX IV.--Continued.

Cat. Number	N	Coll. Date	Tag identification	DFA identification	*P*	Elev. (m)	State	Museum
10917	8	10-Jul-07	*Z. p. princeps*	*Z. p. princeps*	0.849	2,896	CO	CU
10918	8	11-Jul-07	*Z. p. princeps*	*Z. p. princeps*	0.999	2,896	CO	CU
5270	8	26-Jul-45	*Z. p. princeps*	*Z. p. princeps*	1.000	2,902	CO	CU
14226	4	23-Jun-60	*Z. p. princeps*	*Z. p. princeps*	0.921	2,902	CO	CU
14227	8	31-May-60	*Z. p. princeps*	*Z. p. princeps*	0.679	2,902	CO	CU
5273	4	23-Aug-47	*Z. p. princeps*	*Z. p. princeps*	0.978	2,908	CO	CU
91354	8	21-Aug-47	*Z. p. princeps*	*Z. p. princeps*	0.996	3,002	WY	KU
17575	8	28-Aug-46	*Z. p. princeps*	*Z. p. princeps*	0.956	3,047	WY	KU
17576	4	28-Aug-46	*Z. p. princeps*	*Z. p. princeps*	0.969	3,047	WY	KU
17577	8	29-Aug-46	*Z. p. princeps*	*Z. p. princeps*	0.893	3,047	WY	KU
17578	8	30-Aug-46	*Z. p. princeps*	*Z. p. princeps*	0.892	3,047	WY	KU
17579	4	30-Aug-46	*Z. p. princeps*	*Z. p. princeps*	0.999	3,047	WY	KU
17580	2	31-Aug-46	*Z. p. princeps*	*Z. p. princeps*	1.000	3,047	WY	KU
17581	4	1-Sep-46	*Z. p. princeps*	*Z. p. princeps*	0.992	3,047	WY	KU
17582[b]	**8**	**1-Sep-46**	***Z. p. princeps***	***Z. h. preblei***	**0.457**	**3,047**	**WY**	**KU**
5968	4	6-Apr-50	*Z. p. princeps*	*Z. p. princeps*	1.000	3,048	CO	CU
5969	8	6-Apr-50	*Z. p. princeps*	*Z. p. princeps*	1.000	3,048	CO	CU
5970	4	6-Apr-50	*Z. p. princeps*	*Z. p. princeps*	1.000	3,048	CO	CU
5397	8	24-Jun-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,109	CO	CU
4970	8	16-Aug-41	*Z. p. princeps*	*Z. p. princeps*	0.877	3,139	CO	DM
4971	8	16-Aug-41	*Z. p. princeps*	*Z. p. princeps*	0.985	3,139	CO	DM
27666	8	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
27667	8	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
27668	8	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
27669	8	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
27670	8	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
14370	8	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,182	CO	CU
14372	8	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,182	CO	CU
14373	8	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,182	CO	CU
14374	8	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,182	CO	CU
14375	8	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	0.967	3,182	CO	CU
14365	8	8-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,194	CO	CU
14366	8	8-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,194	CO	CU
14367	8	9-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,194	CO	CU

APPENDIX IV.--Continued.

Cat. Number	N	Coll. Date	Tag identification	DFA identification	*P*	Elev. (m)	State	Museum
14368	8	9-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,194	CO	CU
17573	4	1-Sep-46	*Z. p. princeps*	*Z. p. princeps*	0.999	3,230	WY	KU
13737	8	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	1.000	3,358	CO	CU
13739	4	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	0.999	3,358	CO	CU
13740	4	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	0.998	3,358	CO	CU
13742	4	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	0.987	3,358	CO	CU
13744	8	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	1.000	3,358	CO	CU
13741	8	4-Aug-31	*Z. p. princeps*	*Z. p. princeps*	1.000	3,844	CO	CU
1053[b]	**4**	**1-Sep-13**	***Z. p. princeps***	***Z. h. preblei***	**0.500**		**CO**	**DM**

[a] The measurements used in DFA were lstibw, palbre, pallen, lmtrlen, masma, and lm1fold (see Appendix II for a key to abbreviations).

[b] Highlighted specimens were reidentified when DFA was run separately for each set of measurements and then posterior probabilities averaged.

APPENDIX V

Specimen museum tag identification, discriminant function[a] analysis identification, and the associated posterior probability that a specimen was a *Zapus princeps princeps* for the initial sample of 105 *Zapus* specimens from Colorado and southeastern Wyoming. A single DFA was run for the mean of each set of measurements.

Cat. Number	Coll. Date	Tag identification	DFA identification	*P*	Elev. (m)	State	Museum
5105	17-Aug-46	*Z. p. princeps*	*Z. p. princeps*	1.000	1,506	CO	CU
2971	3-Sep-35	*Z. h. preblei*	*Z. h. preblei*	0.000	1,527	CO	DM
2394	7-Jan-30	*Z. h. preblei*	*Z. h. preblei*	0.000	1,553	CO	DM
5210	3-Aug-47	*Z. h. preblei*	*Z. h. preblei*	0.000	1,554	CO	CU
503	5-May-08	*Z. h. preblei*	*Z. h. preblei*	0.000	1,609	CO	CU
9564	13-Aug-98	*Z. h. preblei*	*Z. h. preblei*	0.000	1,615	CO	DM
9578	17-Jul-97	*Z. h. preblei*	*Z. h. preblei*	0.000	1,625	CO	DM
17733	14-Sep-91	*Z. h. preblei*	*Z. h. preblei*	0.000	1,625	CO	CU
1225	30-May-14	*Z. h. preblei*	*Z. h. preblei*	0.000	1,646	CO	CU
9314	16-Jul-97	*Z. h. preblei*	*Z. h. preblei*	0.000	1,646	CO	DM
9843	10-Jul-98	*Z. h. preblei*	*Z. h. preblei*	0.000	1,675	CO	DM
6634	17-Oct-09	*Z. h. preblei*	*Z. h. preblei*	0.195	1,676	CO	DM
9204	28-Aug-97	*Z. h. preblei*	*Z. h. preblei*	0.000	1,703	CO	DM
9205	26-Aug-97	*Z. h. preblei*	*Z. h. preblei*	0.000	1,703	CO	DM
9570[b]	**5-Jun-98**	***Z. h. preblei***	***Z. h. preblei***	**0.007**	**1,730**	**CO**	**DM**
9573	6-Aug-98	*Z. h. preblei*	*Z. h. preblei*	0.028	1,730	CO	DM
9875	16-Jun-99	*Z. h. preblei*	*Z. h. preblei*	0.038	1,730	CO	DM
9876	11-Sep-99	*Z. h. preblei*	*Z. h. preblei*	0.003	1,730	CO	DM
9878	3-Oct-99	*Z. h. preblei*	*Z. h. preblei*	0.001	1,730	CO	DM
17196	6-Aug-88	*Z. h. preblei*	*Z. h. preblei*	0.000	1,737	CO	CU
9561	13-Jul-98	*Z. h. preblei*	*Z. h. preblei*	0.115	1,780	CO	DM
9853	15-Sep-99	*Z. h. preblei*	*Z. h. preblei*	0.000	1,796	CO	DM
9857[b]	**26-Aug-99**	***Z. h. preblei***	***Z. p. princeps***	**0.971**	**1,796**	**CO**	**DM**
9203	31-Aug-95	*Z. h. preblei*	*Z. h. preblei*	0.000	1,814	CO	DM
17001	6-Jul-89	*Z. h. preblei*	*Z. h. preblei*	0.004	1,829	CO	CU
9316	2-Aug-96	*Z. p. princeps*	*Z. p. princeps*	1.000	1,878	WY	DM
10913	6-Jul-03	*Z. p. princeps*	*Z. p. princeps*	1.000	1,890	CO	CU
9312	16-Jul-97	*Z. h. preblei*	*Z. h. preblei*	0.000	1,951	CO	DM
9576[b]	**8-Jun-98**	***Z. h. preblei***	***Z. p. princeps***	**0.996**	**1,960**	**CO**	**DM**
9577	10-Sep-98	*Z. h. preblei*	*Z. h. preblei*	0.049	1,960	CO	DM

APPENDIX V.—-Continued.

Cat. Number	Coll. Date	Tag identification	DFA identification	P	Elev. (m)	State	Museum
17002	7-Sep-90	*Z. h. preblei*	*Z. h. preblei*	0.000	1,963	CO	CU
5575	23-Jul-47	*Z. p. princeps*	*Z. p. princeps*	1.000	2,012	CO	DM
5576	23-Jul-47	*Z. p. princeps*	*Z. p. princeps*	1.000	2,012	CO	DM
9568	8-Aug-98	*Z. h. preblei*	*Z. h. preblei*	0.000	2,023	CO	DM
10912	4-Jun-03	*Z. p. princeps*	*Z. p. princeps*	1.000	2,057	CO	CU
10914	10-Jul-03	*Z. p. princeps*	*Z. p. princeps*	1.000	2,073	CO	CU
10915	10-Jul-03	*Z. p. princeps*	*Z. p. princeps*	1.000	2,073	CO	CU
9315	24-Aug-97	*Z. h. preblei*	*Z. h. preblei*	0.004	2,103	CO	DM
9313	12-Sep-97	*Z. h. preblei*	*Z. h. preblei*	0.000	2,132	CO	DM
3354	31-Jul-38	*Z. p. princeps*	*Z. p. princeps*	1.000	2,133	CO	DM
9562[b]	**30-Aug-98**	***Z. h. preblei***	***Z. h. preblei***	**0.111**	**2,133**	**CO**	**DM**
9565	12-Jul-98	*Z. h. preblei*	*Z. h. preblei*	0.000	2,133	CO	DM
9579	24-Jul-97	*Z. h. preblei*	*Z. h. preblei*	0.000	2,134	CO	DM
1484	18-Aug-14	*Z. p. princeps*	*Z. p. princeps*	0.998	2,256	CO	DM
1486	2-Sep-14	*Z. p. princeps*	*Z. p. princeps*	1.000	2,256	CO	DM
1488	27-Sep-14	*Z. p. princeps*	*Z. p. princeps*	1.000	2,256	CO	DM
1489	24-Sep-14	*Z. p. princeps*	*Z. p. princeps*	1.000	2,256	CO	DM
9560	31-Oct-98	*Z. p. princeps*	*Z. p. princeps*	1.000	2,377	CO	DM
5271	7-Aug-45	*Z. p. princeps*	*Z. p. princeps*	1.000	2,469	CO	CU
5272	7-Aug-45	*Z. p. princeps*	*Z. p. princeps*	1.000	2,469	CO	CU
10916	7-Jul-01	*Z. p. princeps*	*Z. p. princeps*	1.000	2,515	CO	CU
1229	13-Aug-15	*Z. p. princeps*	*Z. p. princeps*	1.000	2,560	CO	DM
7914	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
7915	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
7917	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
7918	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
7919	31-Jul-91	*Z. p. princeps*	*Z. p. princeps*	1.000	2,624	CO	DM
26500	22-Jun-48	*Z. p. princeps*	*Z. p. princeps*	1.000	2,682	WY	KU
14913	1-Aug-71	*Z. p. princeps*	*Z. p. princeps*	1.000	2,701	CO	CU
14915	2-Aug-71	*Z. p. princeps*	*Z. p. princeps*	1.000	2,701	CO	CU
10920	1-Jul-03	*Z. p. princeps*	*Z. p. princeps*	1.000	2,707	CO	CU
26566	10-Jul-48	*Z. p. princeps*	*Z. p. princeps*	1.000	2,712	WY	KU
10917	10-Jul-07	*Z. p. princeps*	*Z. p. princeps*	1.000	2,896	CO	CU
10918	11-Jul-07	*Z. p. princeps*	*Z. p. princeps*	1.000	2,896	CO	CU

APPENDIX V.—Continued.

Cat. Number	Coll. Date	Tag identification	DFA identification	*P*	Elev. (m)	State	Museum
5270	26-Jul-45	*Z. p. princeps*	*Z. p. princeps*	1.000	2,902	CO	CU
14226	23-Jun-60	*Z. p. princeps*	*Z. p. princeps*	1.000	2,902	CO	CU
14227	31-May-60	*Z. p. princeps*	*Z. p. princeps*	0.552	2,902	CO	CU
5273	23-Aug-47	*Z. p. princeps*	*Z. p. princeps*	1.000	2,908	CO	CU
91354	21-Aug-47	*Z. p. princeps*	*Z. p. princeps*	1.000	3,002	WY	KU
17575	28-Aug-46	*Z. p. princeps*	*Z. p. princeps*	1.000	3,047	WY	KU
17576	28-Aug-46	*Z. p. princeps*	*Z. p. princeps*	1.000	3,047	WY	KU
17577	29-Aug-46	*Z. p. princeps*	*Z. p. princeps*	1.000	3,047	WY	KU
17578	30-Aug-46	*Z. p. princeps*	*Z. p. princeps*	1.000	3,047	WY	KU
17579	30-Aug-46	*Z. p. princeps*	*Z. p. princeps*	1.000	3,047	WY	KU
17580	31-Aug-46	*Z. p. princeps*	*Z. p. princeps*	1.000	3,047	WY	KU
17581	1-Sep-46	*Z. p. princeps*	*Z. p. princeps*	1.000	3,047	WY	KU
17582[b]	**1-Sep-46**	***Z. p. princeps***	***Z. p. princeps***	**0.800**	**3,047**	**WY**	**KU**
5968	6-Apr-50	*Z. p. princeps*	*Z. p. princeps*	1.000	3,048	CO	CU
5969	6-Apr-50	*Z. p. princeps*	*Z. p. princeps*	1.000	3,048	CO	CU
5970	6-Apr-50	*Z. p. princeps*	*Z. p. princeps*	1.000	3,048	CO	CU
5397	24-Jun-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,109	CO	CU
4970	16-Aug-41	*Z. p. princeps*	*Z. p. princeps*	1.000	3,139	CO	DM
4971	16-Aug-41	*Z. p. princeps*	*Z. p. princeps*	1.000	3,139	CO	DM
27666	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
27667	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
27668	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
27669	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
27670	1-Aug-48	*Z. p. princeps*	*Z. p. princeps*	1.000	3,181	WY	KU
14370	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,182	CO	CU
14372	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,182	CO	CU
14373	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,182	CO	CU
14374	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,182	CO	CU
14375	22-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,182	CO	CU
14365	8-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,194	CO	CU
14366	8-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,194	CO	CU
14367	9-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,194	CO	CU
14368	9-Jul-70	*Z. p. princeps*	*Z. p. princeps*	1.000	3,194	CO	CU
17573	1-Sep-46	*Z. p. princeps*	*Z. p. princeps*	1.000	3,230	WY	KU

APPENDIX V.—-Continued.

Cat. Number	Coll. Date	Tag identification	DFA identification	*P*	Elev. (m)	State	Museum
13737	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	1.000	3,358	CO	CU
13739	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	1.000	3,358	CO	CU
13740	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	1.000	3,358	CO	CU
13742	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	1.000	3,358	CO	CU
13744	15-Jul-31	*Z. p. princeps*	*Z. p. princeps*	1.000	3,358	CO	CU
13741	4-Aug-31	*Z. p. princeps*	*Z. p. princeps*	1.000	3,844	CO	CU
1053	**1-Sep-13**	***Z. p. princeps***	***Z. p. princeps***	**1.000**		**CO**	**DM**

[a] The measurements used in DFA were lstibw, palbre, pallen, lmtrlen, masma, and lm1fold (see Appendix II for a key to abbreviations).
[b] Highlighted specimens include specimens that were reidentified when DFA was run separately for each set of measurements and then posterior probabilities averaged and specimens reidentified when a single DFA was run for the mean of each set of measurements.

APPENDIX VI

Mean cranial and dental measurements used in the DFA for low-elevation Wyoming specimens. See Appendix II for a key to abbreviations.

Cat. number	Elev. (m)	lstibw	masma	palbre	pallen	lmtrlen	lm1fold
1827	1,835	1.87	8.67	3.23	8.36	4.07	1.00
27937[a]	1,957	1.72	8.75	3.09	.	3.88	0.25
27938	1,957	2.09	9.26	3.62	8.88	3.61	0.00
27939	1,957	2.00	9.45	3.47	8.88	3.96	1.00
27940	1,957	1.99	8.76	3.13	8.34	3.85	0.50
27941	1,957	2.31	9.11	3.36	8.56	3.79	1.00
27942	1,957	2.00	8.99	3.29	8.70	3.81	0.50
27943	1,957	2.12	8.94	3.25	8.16	3.83	1.00
27944	2,041	2.22	9.12	3.18	8.44	4.02	1.00
27671	2,060	1.89	8.99	3.20	8.70	3.67	0.25
1822	2,195	2.39	9.01	3.67	9.20	4.06	0.00
1823	2,195	2.14	9.31	3.59	9.37	3.93	0.50
1824	2,195	2.45	9.17	3.66	9.59	3.89	0.00
15856	2,195	2.45	8.87	3.35	9.09	4.15	0.00
15857	2,195	2.20	9.31	3.63	9.22	4.14	0.00
15858[a]	2,195	.	9.00	3.57	9.03	3.51	0.50
26505[a]	2,195	.	9.27	3.54	9.41	4.08	0.00
26506[a]	2,195	.	9.30	3.58	9.05	4.14	0.00
1826	2,256	2.53	9.19	3.69	9.28	4.25	0.00
1825	2,499	2.43	9.21	4.00	9.56	4.03	0.00

[a] DFA could not be performed on these specimens due to skull damage and the resulting missing measurements.